Climate Cycles Drive Aquatic Ecologic Changes in the Fort McMurray Region of Northern Alberta, Canada

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Summary

Understanding ecologic response to climate cycles will aid in defining current and future ecological changes associated with climate change and allow for a differentiation between climate-driven versus anthropogenic driven environmental stresses.

The paleoecological record from a northern Canadian lake located 40 km east of the Athabasca Oil Sands operation records a benthic stress-induced ecological response to climate cycles such as the El Niño Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO). Arcellacea (testate lobose amoebae) preserved in a freeze core obtained from “ALE”, an upland lake in Northeastern Alberta, Canada, were used to reconstruct climate and associated benthic response since 1875 A.D. ALE is situated in a boreal wetland environment where inorganic sediment delivery is overwhelmingly dominated by surface overland flow transport during spring melt. Arcellacea are benthic protists that are excellent indicators of aquatic ecology. Relationships between arcellacean family groupings which represent either healthy or stressed environmental conditions were compared to instrumental climate indices. Modeling using wavelet analysis identified strong ENSO cycles in all arcellacean proxies and weaker PDO cycles in only the healthy ecosystem indicator. The ENSO phenomenon in the tropical Pacific Ocean drives the largest interannual variation in climate across western Canada, and in the study region has been associated with fluctuations in winter precipitation and temperature. The healthy ecosystem indicators decreased in response to positive El Niño and PDO conditions, which are characteristic of decreased precipitation and therefore nutrient input to boreal lakes.

The relationship between arcellaceans and climate anomalies shows that climate driven variations in nutrient input influence boreal aquatic ecology. The link between aquatic ecology and climate has significant implications on oil sands risk assessment and the determination of reclamation endpoints.

Introduction

Natural climate variation operates over long- to short-timescales and is an important controlling factor in ecosystem dynamics, making characterization of baseline climate variability a critical component of climate and environmental change studies (Solanki et al., 2004). Evaluating the sensitivity of lake hydrology and ecosystems to imposed perturbations such as climate transitions is necessary for characterizing ecosystem responses to future climate changes (Kern et al., 2013) and to differentiate natural vs. anthropogenic ecological stress.

Local Climate

External climatic controls over precipitation in Alberta appear to be related to the same factors that influence the western coast of Canada, such as the jet stream and ENSO (Oh et al., 2003), and global-scale teleconnections such as the PDO and AMO (Whited et al. 2007; McCabe et al., 2008). In general, during positive (negative) ENSO and PDO times the province of Alberta experiences winter precipitation below (above) normal, creating smaller (larger) snow packs and therefore less (more) freshet which contribute strongly to nutrient input to lakes (McCabe et al., 2008). This is interpreted to be due to the warmer (colder) waters occurring off the coast of western North America during positive (negative) ENSO and PDO phases (Mwale et al., 2009).

Study Area

The study lake (informally named "ALE") is a small upland kettle lake located approximately 40 km east of Athabasca Oil Sands mining operations within the Athabasca river basin.

ALE has no human settlements or roads within the watershed. Sedimentological fluctuations and changes in arcellacean assemblages can thus be viewed as the result of ecosystem perturbations and cycles that may be either linked to regional scale climate forcing or anthropogenic impact (e.g. Campbell et al. 1998; Kern et al., 2013).

ALE Hydrologic Link to Climate Cycles

Sedimentary inputs to boreal lakes such as ALE are largely a reflection of the hydrological regime at the time of deposition, which is primarily a function of the local hydrological cycle, in particular the freshet period (Campbell et al. 1998). Therefore changes in sediment input volume and magnitude to ALE are proxies for accumulated winter precipitation. Precipitation in Alberta has been liked to ENSO and PDO activity (Barron and Anderson, 2011). At ALE, during negative (positive) ENSO and PDO phases the study region experiences winter precipitation below (above) normal (McCabe et al., 2008), creating decreased (increased) winter snow packs leading to decreased (increased) freshet. The precise nature of how the freshet impacts ALE are detailed in Gammon et al (submitted).

Ecologic Indicators

Arcellacea, informally described as thecamoebians, rhizopods, testaceans and testate amoebae, are primarily benthic protists that constitute an important component of the sediment/water interface and epibenthic community within the microbial trophic level in lakes and wetlands (Neville et al. 2010a, 2010b; Roe, et al. 2010; Elliott et al. 2012).

Methods

Please see: Neville, L.A, 2014, high resolution paleolimnology of lakes in the Athabasca Oil Sands mining region, Alberta, Canada, Carleton U. doctoral thesis for a full description of the methods and results.

Examples

Relationship to Climate Indices

Many species within the arcellacean family Difflugiidae are sensitive to ecological stress, often related to temperature, substrate type or nutrient availability, whereas Centropyxidae taxa thrive in all but the most highly stressed environments (Roe et al. 2010; Neville et al. 2010, 2011; McCarthy et al., 1996). For an indication of the overall ecological changes archived in ALE we grouped the arcellacean species observed by the families Centropyxidae and Difflugiidae.

Correlation analysis of the arcellacean data against the climate proxies produced strong relationships between the arcellaceans and the PDO, Nino 3.4 and AMO data (Table 1).

Table 1: Spearman's rank correlation coefficient analysis of the arcellacean groupings and the climate variables (Niño 3.4, instrumental PDO, and AMO; available at www.esrl.noaa.gov). The annual Nino 3.4 data is labeled with a Y, the Nino 3.4 data is also collated into seasonal groupings of January- March (labeled JFM) and July- September (labeled JAS). Note the inverse relationship between the arcellacean species groupings of centropyxids and difflugiids with the climate proxies. Italic numbers are significant at the P < 0.001 level.

	PDO instrumental	Nino 3.4 Y	Nino 3.4 JFM	Nino 3.4 JAS	AMO
Total centropyxids	0.389	*0.762*	*0.574*	*0.848*	-0.017
Total difflugiids	-0.396	*-0.554*	*-0.334*	*-0.602*	*0.475*

In most cases the spearman's rank correlation coefficient analysis produced opposite polarity correlations (inverse relationships) between the arcellacean groupings and measured climate variable (Tables 1 & 2). The negative relationship between total difflugiids (higher sensitivity, lower tolerance species) and ENSO and PDO events suggests that this population favors La Niña and negative PDO conditions (wetter and cooler). El Niño and positive PDO conditions (drier and warmer) form a positive relationship with the opportunistic centropyxids (Table 2). The observed specific ecological connections related to ENSO and PDO cycle phases suggest climate anomalies influence benthic ecological changes.

Table 2: Summary of environmental conditions and ecological response related to the various climate drivers influencing the study region.

ENSO & PDO	
Positive Phase (El Niño)	↑ temperature, ↓ snowpack, ↓ difflugiids, ↑ centropyxids (=↑ ecologic stress)
Negative Phase (La Niña)	↓ temperature, ↑ snowpack, ↑ difflugiids, ↓ centropyxids (=↓ ecologic stress)

Eco-hydrologic Model

The correlations between the arcellacean data and the climate proxies suggests that climate influences northern boreal lake ecology. The opposite polarity nature of these correlations suggests specific ecological relationships with the different phases of the climate anomalies. The ecological nature of a particular boreal lake depends not only on its physical setting, but also on inputs to the system (Schindler, 1997). Boreal lakes are highly productive and consume high concentrations of nutrients, so the primary productivity of these lakes is dependent upon the concentrations of nutrients entering the lake (Schindler et al., 1996).

Climate anomalies therefore influence input to boreal lakes by affecting precipitation and fluid flow to the system. In ALE a decrease in the environmentally sensitive difflugiids is associated with positive ENSO (El Niño) and positive PDO conditions (Tables 1-2). ENSO and PDO activity in western and central Canada are both manifested by a decrease in wintertime precipitation associated with El Niño and increased precipitation associated with La Niña (Barron and Anderson 2011). A decrease in winter precipitation leads to a decrease in freshet so at the study site directly correlates to a decrease in overland flow/runoff and therefore input to the lake. Arcellaceans are primary consumers (Neville et al. 2010b; Roe, et al. 2010; Elliott et al. 2012), therefore the lack of nutrients supplied to the lake during El Niño creates a higher stress system less favorable to difflugiids, decreasing the populations and allowing for an increase in the opportunistic centropyxid type arcellaceans (Table 1). This is consistent with observations by others that opportunistic arcellacean species such as centropyxids are abundant during times of unfavorable environmental conditions associated with low nutrient availability (McCarthy et al. 1995; Neville et al. 2010b).

Conclusion

The benthic arcellacean ecological data collected from a freeze core in ALE, a lake in northern Alberta, located 40 km east of the Athabasca Oil Sands operation indicates that these lakes are subjected to cyclic ecological pressures driven by climatic cycles, which for this lake can be linked to ENSO, PDO and AMO. Specifically, precipitation is the most important external climate forcing mechanism in the area and primarily impacts winter snowpack accumulation. The magnitude and duration of the spring melt in turn determines the levels of nutrient input into the lake. It is the variability of nutrient input that drives the observed cycles in arcellacean productivity and therefore ecological conditions. Based on this data it appears that climate is a major driver of aquatic ecological changes in the oil sands region and thus should be included in models assessing anthropogenic impact. Additionally the link between aquatic ecology and climate has significant implications on oil sands risk assessment and the determination of reclamation endpoints.

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